

# **Simulation Based Studies of Low Latency Teleoperations for NASA Exploration Missions**

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Human exploration of Mars will involve both crewed and robotic systems. Many mission concepts involve the deployment and assembly of mission support assets prior to crew arrival on the surface. Some of these deployment and assembly activities will be performed autonomously while others will be performed using teleoperations. However, significant communications latencies between the Earth and Mars make teleoperations challenging. Alternatively, low latency teleoperations are possible from locations in Mars orbit like Mars' moons Phobos and Deimos.

To explore these latency opportunities, NASA is conducting a series of studies to investigate the effects of latency on telerobotic deployment and assembly activities. These studies are being conducted in laboratory environments at NASA's Johnson Space Center (JSC), the Human Exploration Research Analog (HERA) at JSC and the NASA Extreme Environment Mission Operations (NEEMO) underwater habitat off the coast of Florida. The studies involve two human-in-the-loop interactive simulations developed by the NASA Exploration Systems Simulations (NExSyS) team at JSC. The first simulation investigates manipulation related activities while the second simulation investigates mobility related activities.

The first simulation provides a simple real-time operator interface with displays and controls for a simulated 6 degree of freedom end effector. The initial version of the simulation uses a simple control mode to decouple the robotic kinematic constraints and a communications delay to model latency effects. This provides the basis for early testing with more detailed manipulation simulations planned for the future. Subjects are tested using five operating latencies that represent teleoperation conditions from local surface operations to orbital operations at Phobos, Deimos and ultimately high Martian orbit. Subject performance is measured and correlated with three distance-to-target zones of interest. Each zone represents a target distance ranging from beyond 10m in Zone 1, through 1 cm to contact in Zone 5 with a step size factor of 10. Collected data consists of both objective simulation data (time, distance, hand controller inputs, velocity) and subjective questionnaire data.

The second simulation provides a simple real-time operator interface with displays and control of a simulated surface rover. The rover traverses a synthetic Mars-like terrain and must be

maneuvered to avoid obstacles while progressing to its destination. Like the manipulator simulation, subjects are tested using five operating latencies that represent teleoperation conditions from local surface operations to orbital operations at Phobos, Deimos and ultimately high Martian orbit. The rover is also operated at three different traverse speeds to assess the correlation between latency and speed. Collected data consisted of both objective simulation data (time, distance, hand controller inputs, braking) and subjective questionnaire data.

These studies are exploring relationships between task complexity, operating speeds, operator efficiencies, and communications latencies for low latency teleoperations in support of human planetary exploration. This paper presents early results from these studies along with the current observations and conclusions. These and planned future studies will help to inform NASA on the potential for low latency teleoperations to support human exploration of Mars and inform the design of robotic systems and exploration missions.